

Large Aperture Multiplexed Diffractive Lidar Optics

Final Report

Contract # NAS5-98062

Dr Richard D. Rallison, PI

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prepared for

Geary K. Schwemmer, Code 912

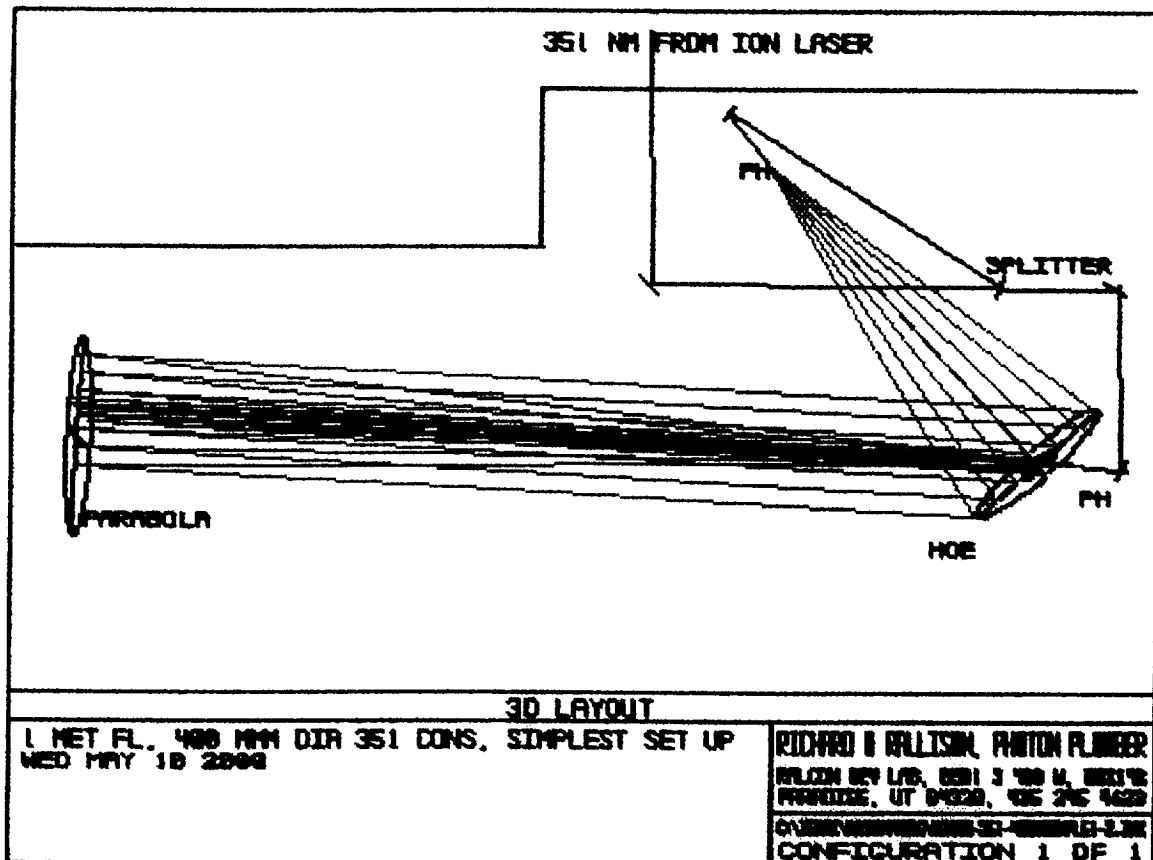
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1. Introduction and project summary

Our primary goal was to design and construct a 1 meter diameter multiplex of 9 HOE facets that together would scan, collect and filter the two or three laser lines of YAG, the fundamental, the second harmonic and the third harmonic. We were to build and deliver two such devices in possibly two different diffractive formats and capture at least 80% of the incident laser radiation in 250 micron or smaller spots. The actual goal for resolution was 50 micro radians or 125 micron spots at a 2.5 meter focal length. In addition we were to make some 400 mm dia UV HOES of about the same design and 1 meter focal length that could be used in the existing HARLEY configuration. The multiplexing scheme was investigated using mechanical assembly of individual shots and found to be cumbersome and unnecessary. A multiplexing scheme consisting of moving a mask in front of the recording plane and shooting individual areas sequentially on a single substrate proved to be more practical and was exclusively pursued throughout most of the phase 2 work.

A new building with a UV exposure room and two bays of Vacuum equipment was constructed in the first year and equipped with a 16 foot long by 10 foot wide floating table and an Argon laser outputting at 351.1 nm. We also installed a new 12 by 5 foot table and a visible lines only argon laser in a second room for copy work. A 36 inch diameter parabolic mirror was ordered and constructed at Intermountain Optics to be used as a collimator and was bolted down to one end of the largest table. Coating and processing facilities for up to 36 inch diameter plates were also constructed and successful coatings were made on 36 inch Starphire substrates in the second year. A cold alcohol process was worked out that yielded good efficiency and low scatter at 355 nm. As many fused silica optics and splitters as would be needed were obtained and all optical

and mechanical parts worked well together. The optical designs and arrangements were adjusted as needed as we went along and shooting proceeded in the second year as planned. The results fell far short of the expectations and laser breakdowns were frequent and prolonged.

An error was made in the calculation of the required energy to expose dichromated gelatin in the UV region. The sensitivity did not increase linearly at wavelengths shorter than 400 nm, as was supposed, in fact it decreased slightly so that the required exposure energy was about the same at 351 nm as it was at 458 nm. This miscalculation cost us dearly in photons that were just not available. We upgraded our laser source of UV light twice during the period of performance from 20 to 200 mw at 351 nm and once more after the close of the contract. Three months after the end date we were just able to record successfully at the 40 cm diameter. The 1 meter diameter should fall out from future exposures using the last upgrade to a 5 watt 355 nm pulsed YAG, all prior work was done at 200 mw or less from an Argon laser. Unfortunately the delivery will be delayed by an additional 6 months. A significant effort was made to set all of this up so we have no intention of halting the work as long as the final product is deemed to be useful to NASA and as long as we can continue to make progress.

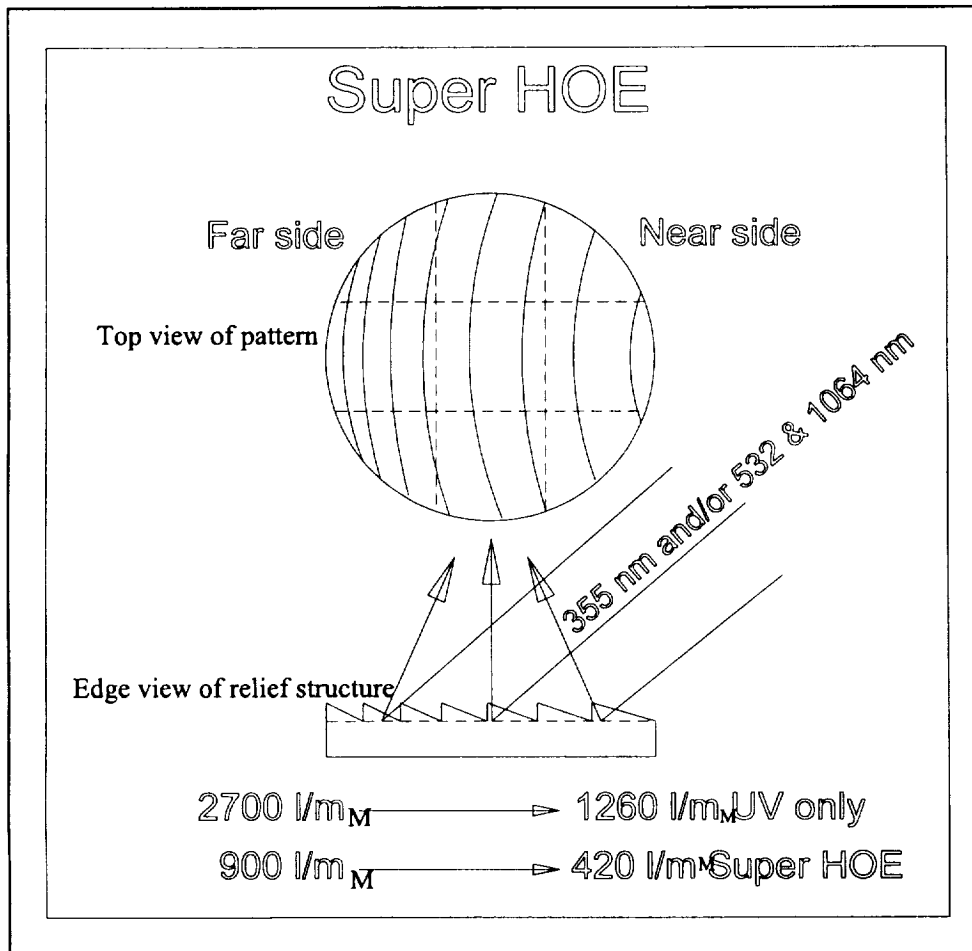
2. Original Design

The original design was to make an etched surface relief structure because it was thought that DCG would always absorb 20 to 40% of the 355 nm radiation. To that end we investigated reactive ion etching, (RIE), and ion sputtering techniques and even bought an 8 inch ion mill and a small reactive ion etcher, believing that this was the only viable approach. We still intended to make nine optical masters in DCG and then optically copy them to 36 individual 7 inch substrates that could be etched in our ion mill. Each facet of the 1 meter assembly was to be about 1/3 of a meter square or very close to 14 inches. All of the facets were designed as 14 inch squares so that exposure, fabrication, assembly and orientation procedures could easily be worked out with a minimum of mistakes. We found in phase I that the resolution of the individual 14 inch facets can be 40 times better than the resolution of a single 1 meter exposure, when using the design rules for time reverse ray tracing (TRRT). This is in large part because the 3rd order Seidel aberrations grow exponentially with decreasing f#. We were designing for an f# of 2.5 in the assembled optic but each individual design is only an f# of 7. This is a very large advantage without which we would probably fail to get 100 micro radian resolution when construction was carried out at 458 nm. In fact it is possible to get less than 50 micro radians with this design, the resolution is most likely limited by fabrication errors and not aberrations.

The first 9 designs were to be for the UV region because it was of most interest to NASA. I hired a consultant to make a spreadsheet design aid that broke the full aperture into 9 sub-apertures and soon found that aberrations were going to be really hard to control beyond about one milliradian for some of the facets. The shift from 458 nm to 355 nm was in the wrong direction for easy design of null optics, one of the first of many surprises to pop out of the design procedure. The more difficult optical designs had to be translated into construction hardware and layouts that could be placed on a single exposure table with 1 mm accumulated

error or better. We were able to do this with some effort but it cost a lot for all the extra hardware, including precision tables. All designs were for transmission elements and ways were found to expose each facet using only refractive components as aberration correction elements. The end result was to be a blazed surface we called a "Super HOE" that could diffract all three YAG wavelengths nearly equally.

The planned surface relief structure for the UV line only was designed but never built. The basic design of the super hoe was also completed. At the far edge of the design where light enters at 45 degrees and exits at 15 degrees the spatial frequency on the surface reached a high of



nearly 2700 l/mm and the line pairs are on the order of one wavelength. This puts the grating structure into the non scalar regime, where only one 1st order can propagate and slanted deep square or rounded grooves or a proper shallow blazed structure would yield high diffraction efficiencies. The deep grooves alone work well in a transmission mode and the blazed sawtooth profile

Figure 1. Super HOE fringe pattern is 1/3 as fine as UV HOE would be.

works best in reflection, even though they will both work in either role with proper attention paid to modulation and finish detail. The blazed efficiency has to fall off slightly at high angles due to shadows, but the exact amount is not derived from geometry alone at these high frequencies and rigorous coupled wave calculations are required. (Not so difficult to do now)

Scalar theory predicts that shadows would knock out 41% of the light, which would be unacceptable but coupled wave theory allows at least 90% in the 1st order. The shadows begin to play a role only when the fringes are much larger than a wavelength, as would be the case for a super HOE on the near side of the HOE where the spatial frequency falls to $1260/3=420$ l/mm or a spacing of 2.38 microns or 6.7 UV wavelengths. The full angle of diffraction here is only 30 degrees for either design but the super HOE design is made to accommodate 1064 nm in the first order, so that the spacing is trippled from the NIR wavelength and clearly this is approaching scaler territory for UV light. The shadow losses at the near edge of the super HOE at 355 nm are given by the scalar relation, losses $= .5 (\lambda^2 / d^2) = .5 (.126/5.66) = 1.1\%$. This is for reflection and transmission would be closer to 2%.

The super HOE design is based on the well known scalar blaze relation where efficiency = 100% when the depth of the sawtooth (T), equals $m\lambda/(n-1)$ or for reflection in air the (n-1) is replaced by 2 and the m is the order of interest. For the first order blaze at 1064 nm the depth will be 532 nm and at that depth the blaze angle is correct for the first order of 1064, the second order of 532 and third order of 355 nm. From this relationship it is obvious that the phase shift in each groove is optimum for all three wavelengths and therefore the efficiency in one common direction will be maximized for each wavelength and only a coupled wave analysis would tell us what that maximum is at each wavelength. In any case the max is more than 90% in each and the problem facing us was controlling fabrication errors in slope and surface roughness sufficiently to satisfy low scattering conditions at the shortest wavelength.

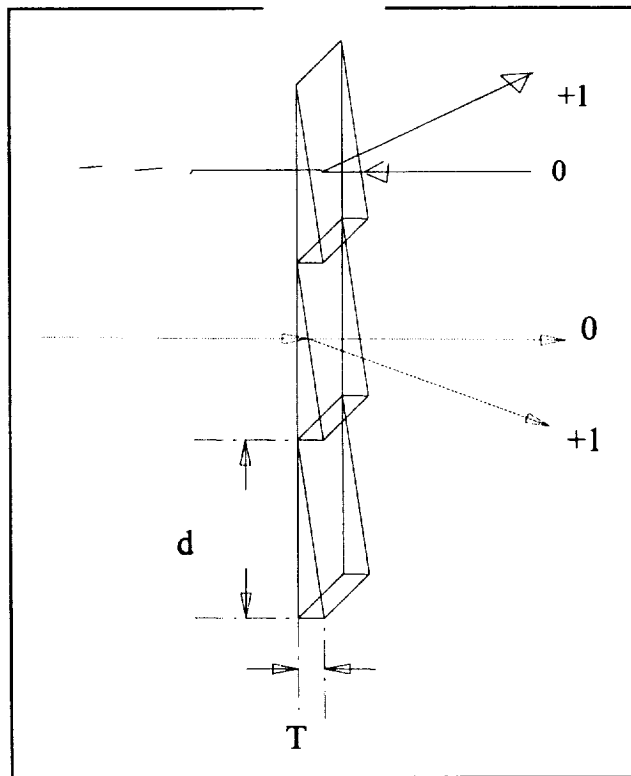


Figure 2. Blazed grating profiles puts most power in one order but not necessarily in the first order, blaze angles determine the order @ lambda.

The path leading to the construction of a "Super HOE" etched in fused silica looked to be far longer and harder to follow than we first predicted. Several alternate routes were then investigated. The masters were always to be made in DCG so it made sense to try to use DCG as a final recording. The trick would be to get more of the strongly absorbing dichromate sensitizer dissolved out of it and find a glass substrate that would work about as well as fused silica.

3. Final Design

The final design was a surprise and resulted from measurements made in DCG on common substrates. I tested all of the glass types and glues we had in stock for transmission at 355 nm in a spectro densitometer. The results are tabulated here:

<u>glass/glue type</u>	<u>thickness</u>	<u>density@355nm</u>	<u>absorption @355nm</u>
fused silica	3 mm	.03 (6% refl)	<u>0</u> (reference 93.3%)
Water white	1 mm	.033	3%
Starphire	6 mm	.03 -.031	<u>1% or less</u>
Solarphire	3 mm	.2	Way too much (30%)
New IR glass	6 mm	.131	19%
Soda Lime	2 mm	.094	12%
Epotek 301	25 um	.005	<u>1% or less</u>
gelatin, processed	5-7 um	.07-.08 on ww	6 to 8%
ww-gel-301-ww	2 mm	.07	8%

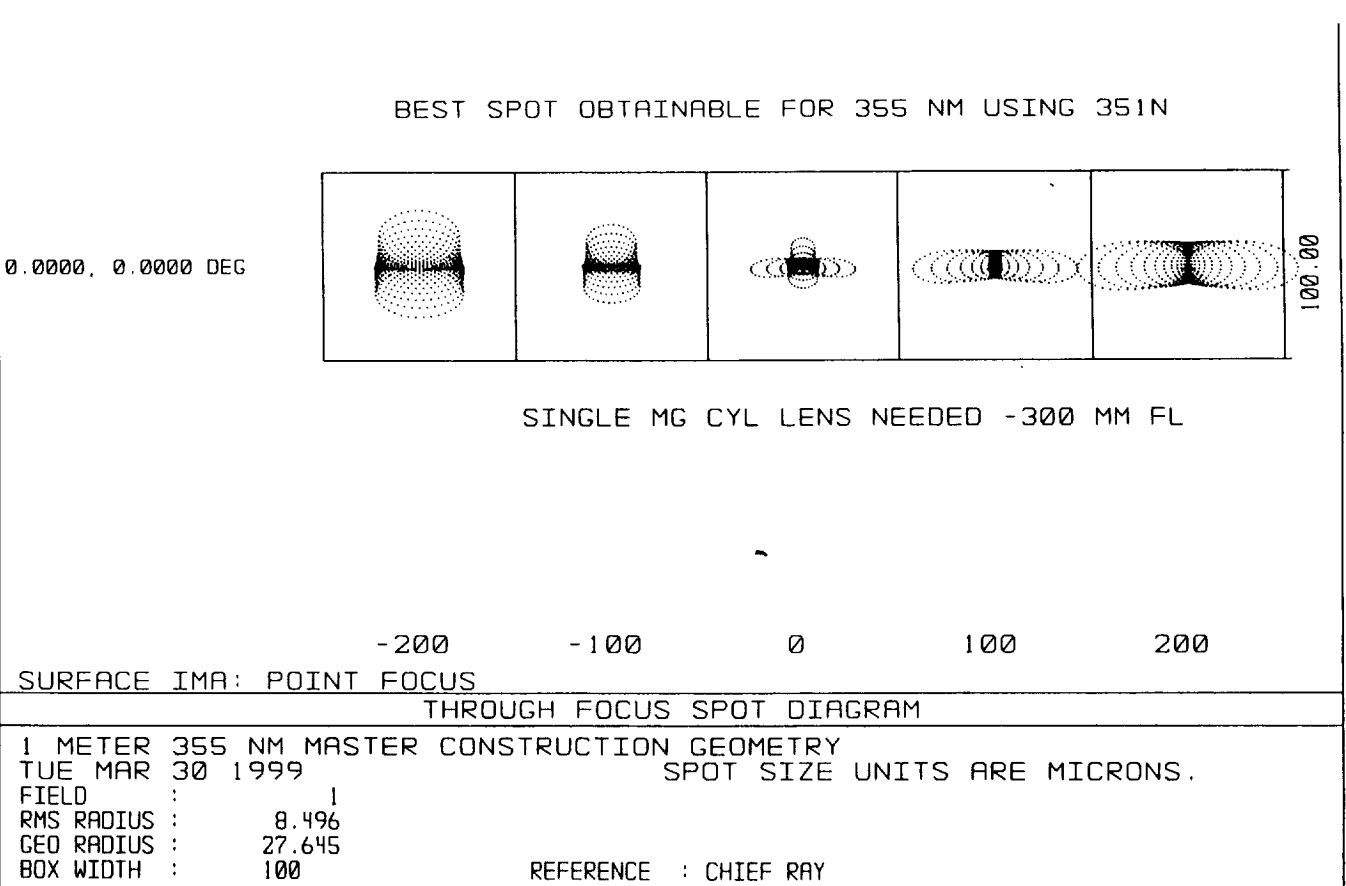
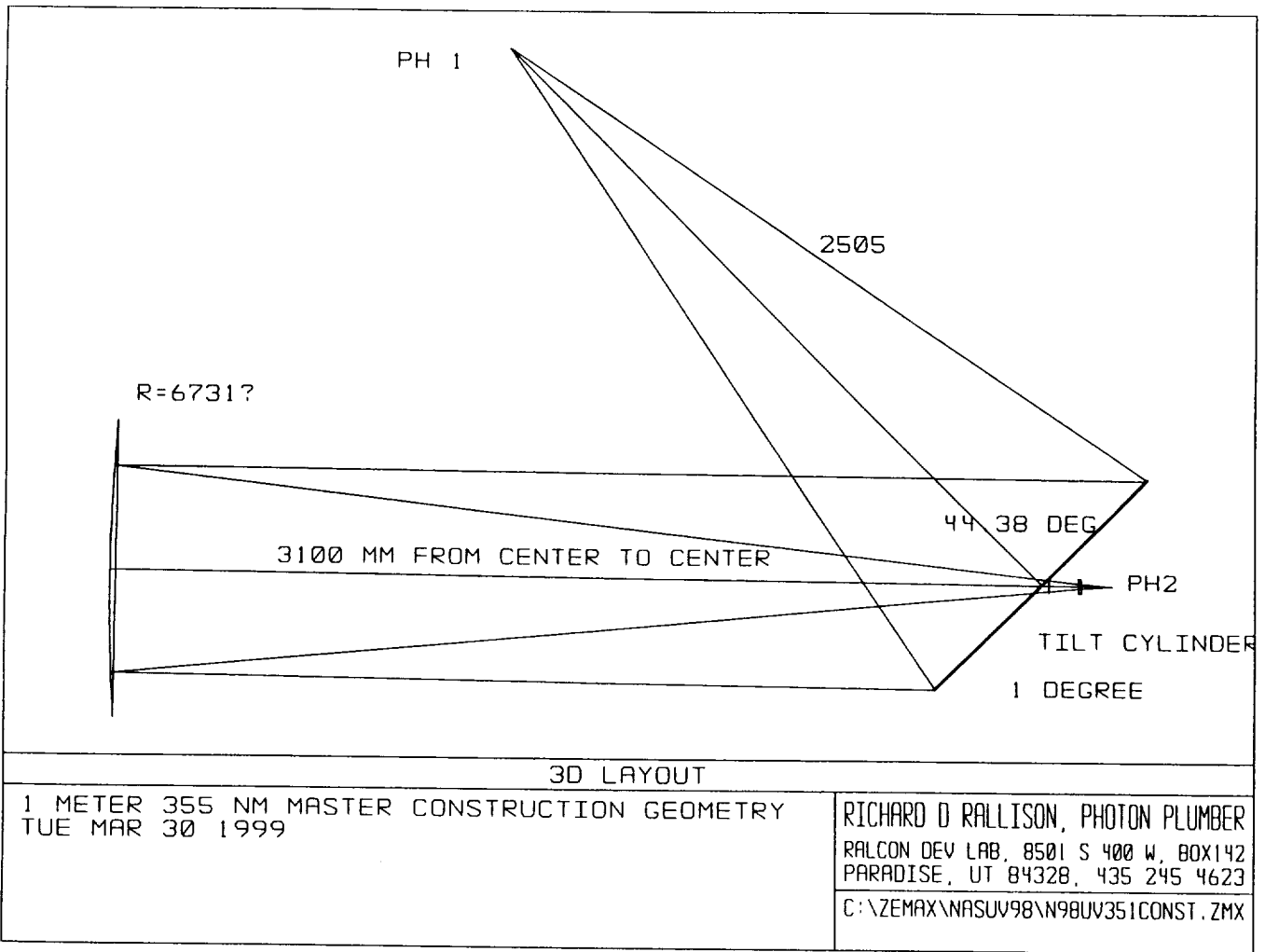
None of the glues other than Epotek 301 and 302 were useful at 355 nm. The 301 is hard to work bubble free but it is an exceptionally strong glue with very good environmental characteristics including the lowest absorption of water of any glue we have ever tested and it will not yellow with UV exposure. The best choice for 1064 and 355 nm together would be fused silica and Epotek 301. The Starphire is an excellent glass for 355 and 532 nm but absorbs about 4 % in 6 mm at 1064 nm. Conceivably we could use a Starphire substrate to glue fused silica pieces down to and not loose more than 4% to absorption. All of the subsequent UV only work has been done as transmission HOEs in 5 microns of DCG. All reflective designs were abandoned when DCG was found to transmit 355 nm. We have used two 6 mm thick sheets of Starphire in each assembly so we are giving up about 10% to absorption and simple single layer MgF AR coatings can go on as a last step resulting in only 1 % loss per interface, making it possible to do better than 85% diffraction efficiency. In practice the scatter in the UV will always result in a smaller number but small improvements can be made to approach 85%. We have delivered several 40 cm HOEs of this type and the last few were laminated with Epotek 301-2, a slower curing variation of 301 that yields the lowest aberrations after glueing. Spot sizes as small as 200 microns have been photographed from these plates.

The final design for a UV only HOE could now be done in gelatin and exposures could be simplified by using the 351 nm or 364 nm line from an argon laser. Very little aberration correction would be needed and the only guess work was in determining the long term stability of the UV lines and the spectral sensitivity of the DCG at those lines. We extrapolated the known and published sensitivity curve into the UV and determined that a small frame ion laser producing just 40 mw of 351 nm could expose a 400 mm diameter plate in about 1 minute, the extrapolation was wrong, much more power was needed. The 351 nm line is also a doublet and both frequencies are always oscillating with the 351.1 line dominating the 351.4 line.

The 36 inch parabola was finished and measured early in 1999 and many designs using it were made. Some were also done using a smaller 20 inch parabola. The 351 nm wavelength made it possible to use only a single negative cylinder in one construction leg for astigmatism correction. The first 36 inch table layout for construction is labeled N98UV351const.zmx and the residual aberrations are seen in the frame below it on page 7. An alternate exposure geometry labeled ~~N98UV351BK7~~ takes up the top half of page 8 and was included because it uses a lens we had on hand and is set up even now for a future shot. A cylindrical lens was also useful in the recording layout of the shorter focal length 400 mm dia optic. My first choice of lenses for recording at 351 nm were fused silica plano-concave. They were less lossey than multi-element spatial filters and yielded small spots on reconstruction as shown on page 9 in file # N99UV351BK7_silica-400MMSETUP.zmx. This was the set up used to create the first weak 400 mm HOE delivered late in 1999. We had only 30 or 40 mw power at 351 to make that recording so we shot it in four quadrants with exposures of 13 minutes in each quadrant and even then it received only about 1/4 of the required energy to be a good exposure. A slightly more compact version is shown on page 10 with a detail of the lens arrangement. No finished shots were ever made with this version.

The negative lens arrangement was abandoned later on when it became clear that a cleaner beam was needed and spatial filters were introduced along with a new contraption we call the aperture scanner. The aperture scanner would not work correctly with a cylindrical element in just one leg so we either had to add another or remove the one we had. In the interest of conserving precious photons a design was arrived at that used no lenses at all. We derived some astigmatism correction from tilting the parabolic mirror which was now smaller and shorter focal length as well. The final exposures were done with the layout shown on page 11, ZEMAX layout # N2000-351-400Vsimple1-1.zmx. The spot grew to about 160 microns but now spatial filters and an aperture scanner could be used, enabling reasonable exposure qualities and parameters.

We bought a third and much larger Argon Laser with almost 200 mw of 351 nm output and could make a suitable scanned exposure in 20 minutes. The first 3 batches of 10 plates yielded no good exposures. The laser remained stable but the table, with a 10 meter path length to keep constant, would simply not hold still for more than about 15 minutes. We had to wait until the weather warmed up a little to get one or two good shots completed. As of this writing one original and one copy of a master has been capped and shaped for shipping. The spot diagram for the original plate is shown in the top half of page 12 with a mm scale next to it. The bottom half are spot photos of the original weak HOE we sent last year. The spots are all about the same size.



BK7 LAYOUT

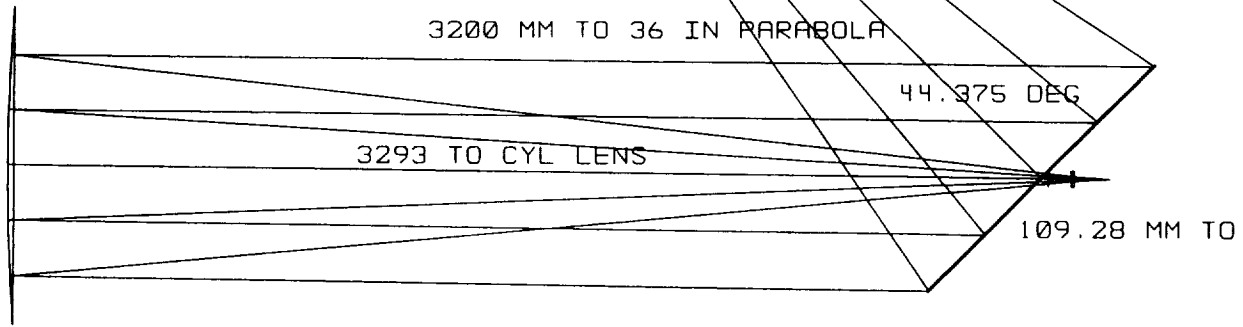
IDEAL CLY LENS IS LQC 018 (SILICA)

2505 MM

-300 MM FL 26 MM BY 60 MM

MAY USE LCN 012 (BK7) AS SUBSTITUTE

TILT LENS 1 DEG CTR CLKW



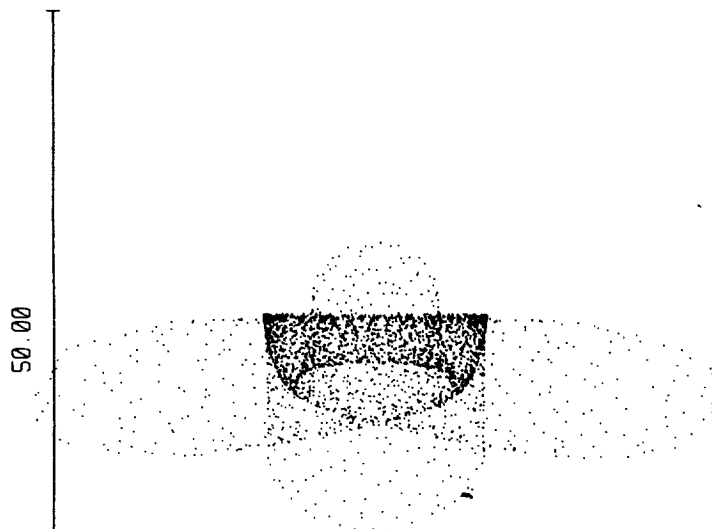
351 NM LAYOUT FOR BEST SPOTS AT 355 NM

3D LAYOUT

1 METER 355 NM MASTER CONSTRUCTION GEOMETRY
THU APR 1 1999

RICHARD D RALLISON, PHOTON PLUMBER
RALCON DEV LAB, 8501 S 400 W, BOX 142
PARADISE, UT 84328, 435 245 4623
C:\ZEMAX\NASUV98\N98UV351BK7.ZMX

OBJ: 0.0000, 0.0000 DEG



BEST SPOT SIZE USING 351.1 NM

WITH LCN 012 BK7 -300 MM FL LENS

IMA: 0.000, 0.007 MM

SURFACE IMA: POINT FOCUS

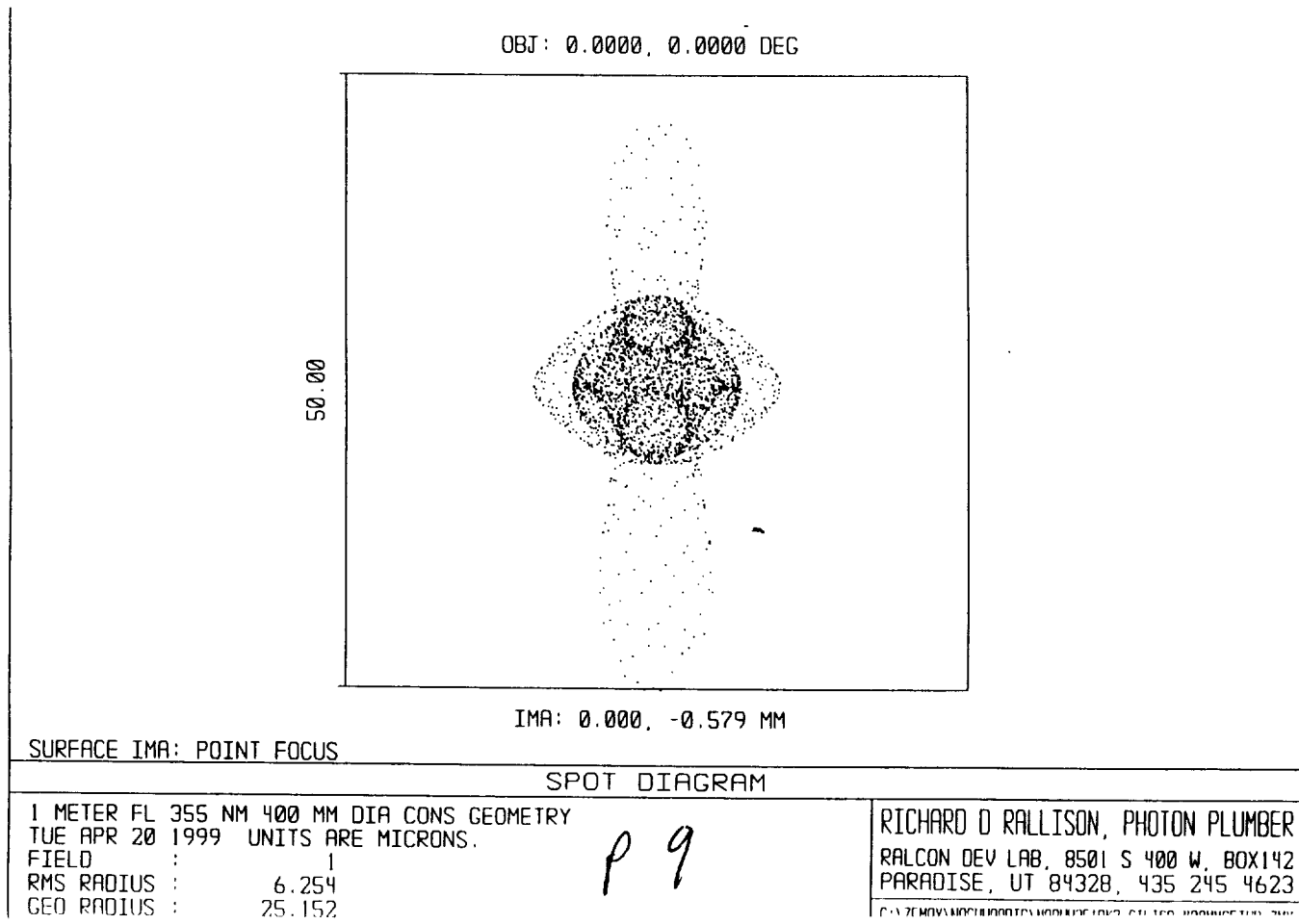
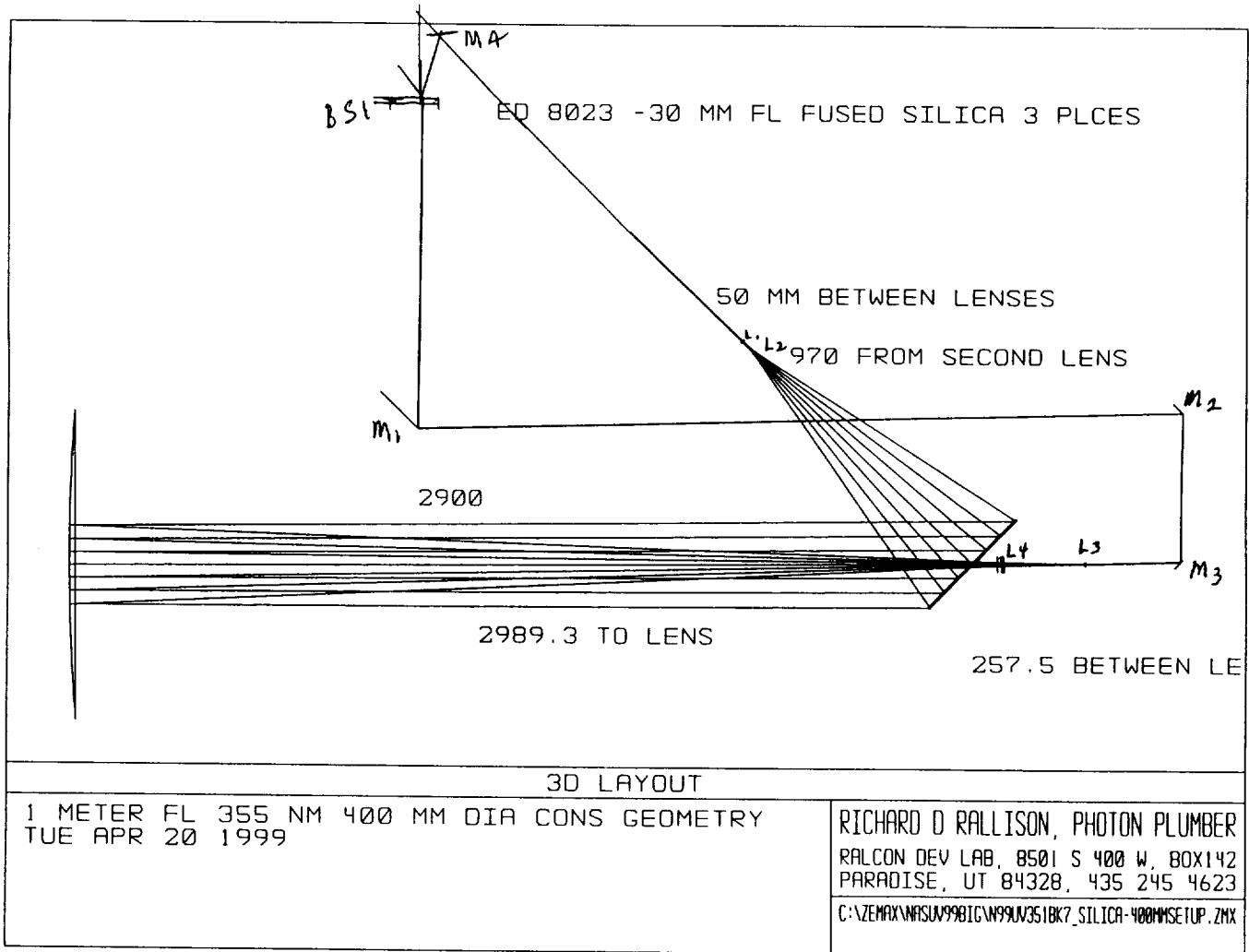
SPOT DIAGRAM

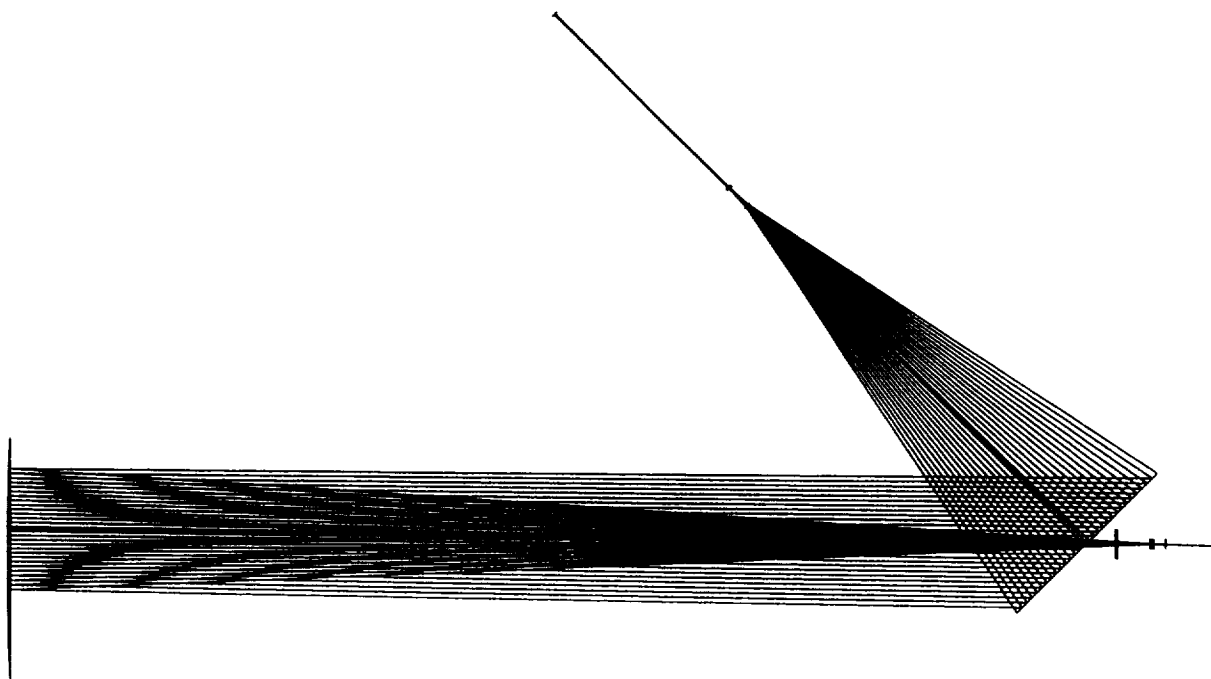
1 METER 355 NM MASTER CONSTRUCTION GEOMETRY
THU APR 1 1999 UNITS ARE MICRONS.

FIELD : 1
RMS RADIUS : 8.342
CFD RADIUS : 27.363

18

RICHARD D RALLISON, PHOTON PLUMBER
RALCON DEV LAB, 8501 S 400 W, BOX 142
PARADISE, UT 84328, 435 245 4623
C:\ZEMAX\NASUV98\N98UV351BK7.ZMX





3D LAYOUT

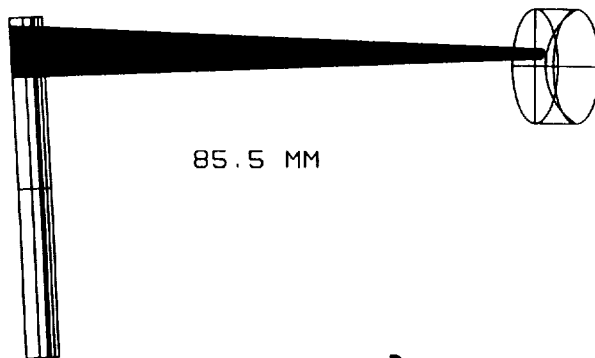
1 MET FL, 400 MM DIA 351 CONS, LCP015, 99MMFL TELE
SAT MAR 4 2000

RICHARD D RALLISON, PHOTON PLUMBER

RALCON DEV LAB, 8501 S 400 W, BOX 142
PARADISE, UT 84328, 435 245 4623

C:\ZEMAX\NASUV99B\N2000-351\CP015-400V99.ZMX
CONFIGURATION 1 OF 1

FROM ABOVE



85.5 MM

3D LAYOUT

1 MET FL, 400 MM DIA 351 CONS, LCP015

SAT MAR 4 2000
SCALE: 1.0000

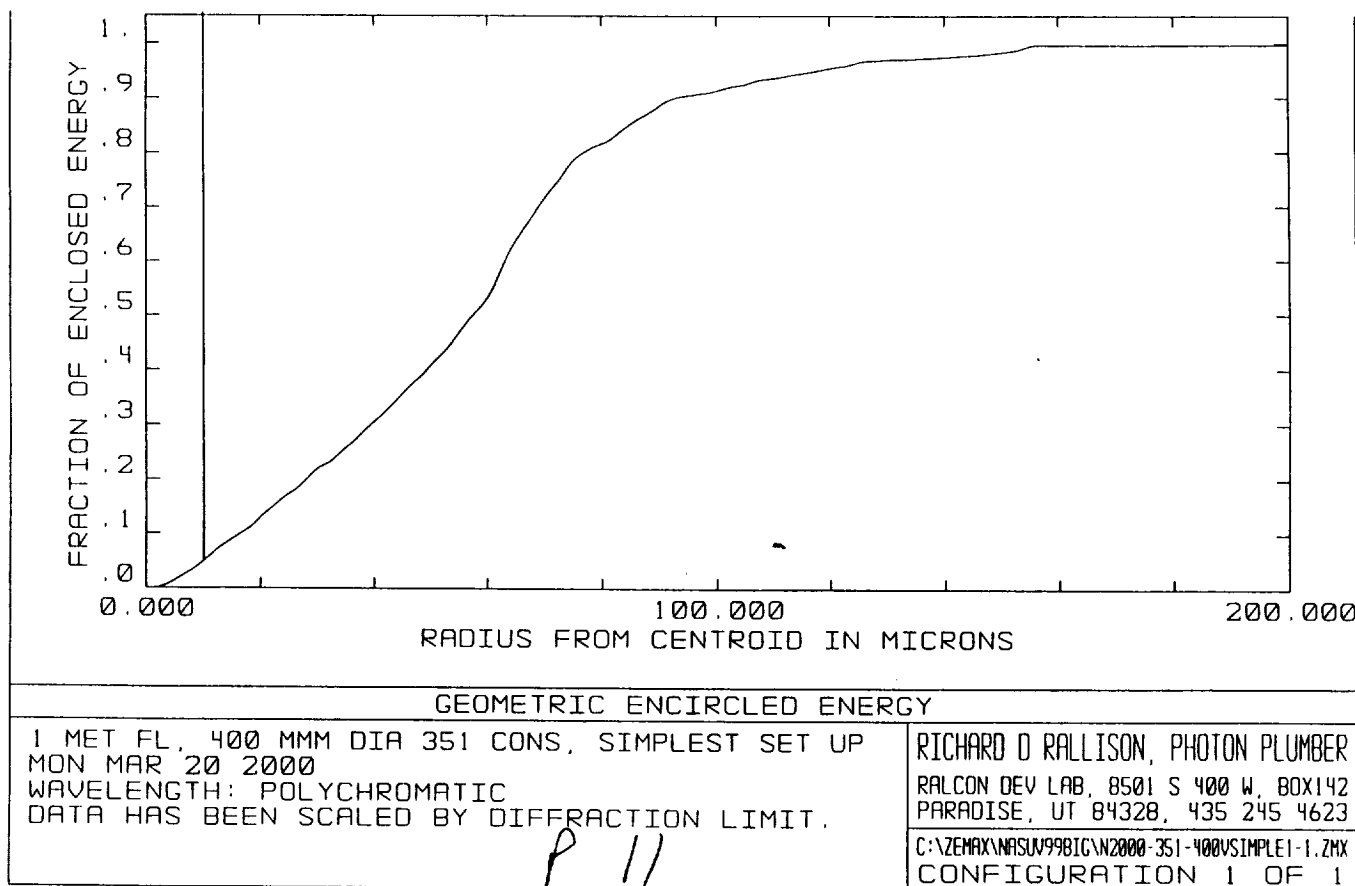
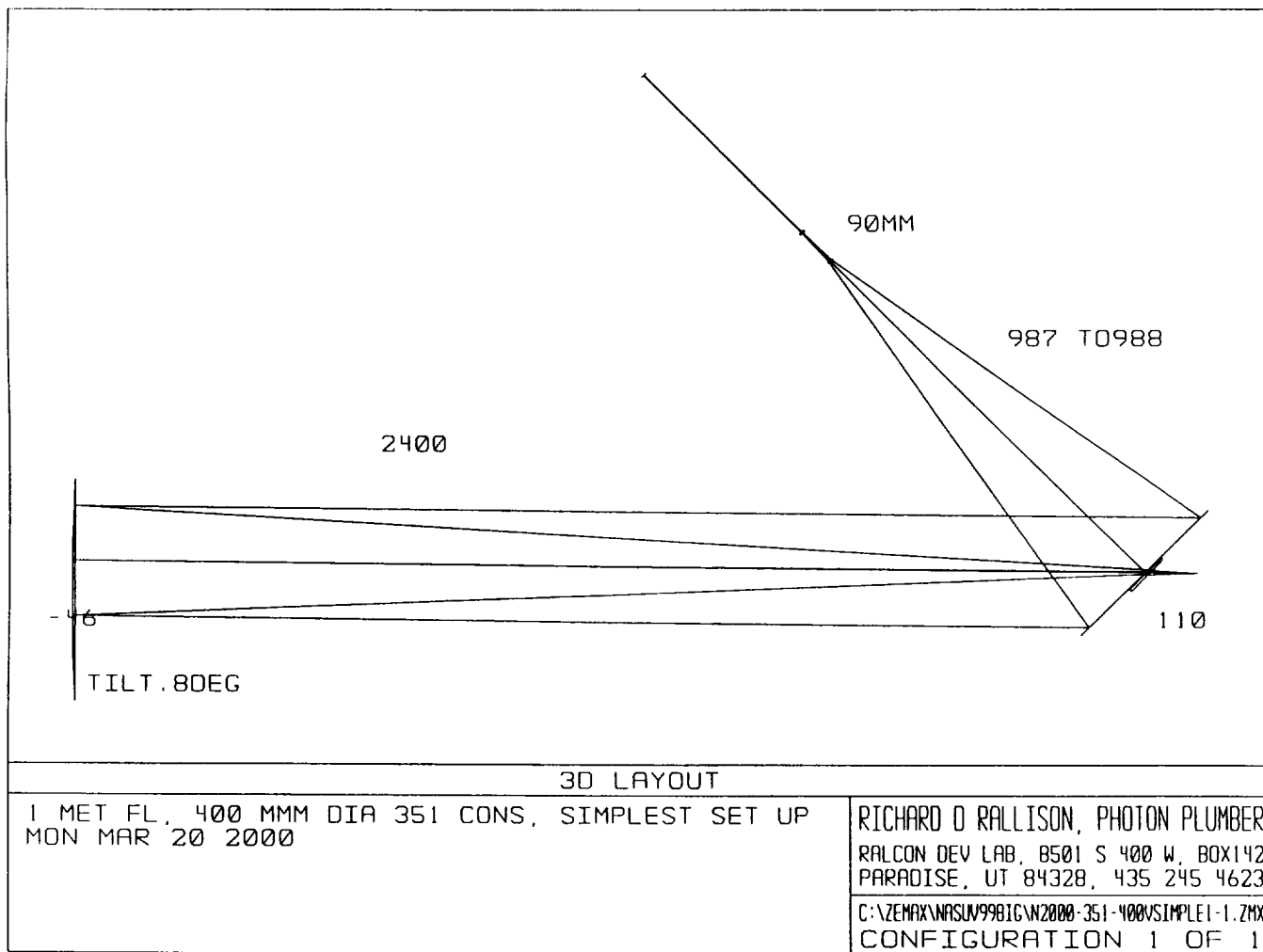
P 10

20.00 MILLIMETERS

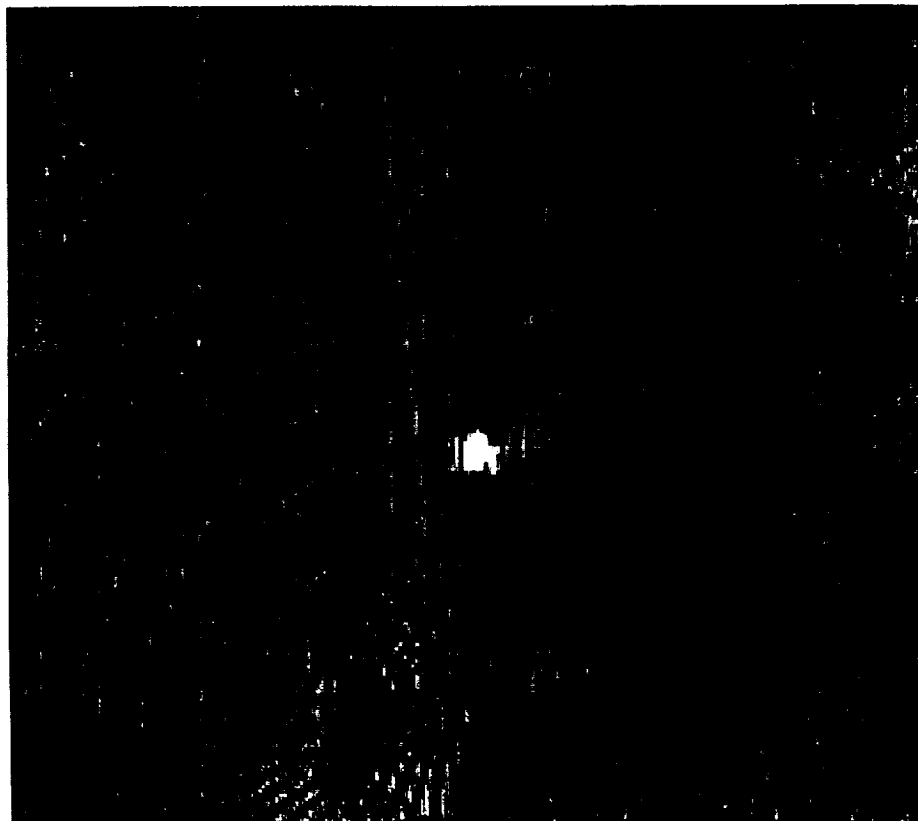
RICHARD D RALLISON, PHOTON PLUMBER

RALCON DEV LAB, 8501 S 400 W, BOX 142
PARADISE, UT 84328, 435 245 4623

C:\ZEMAX\NASUV99B\N2000-351\CP015-400V1.ZMX



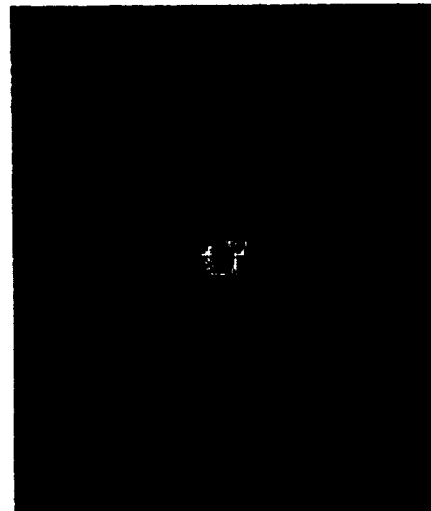
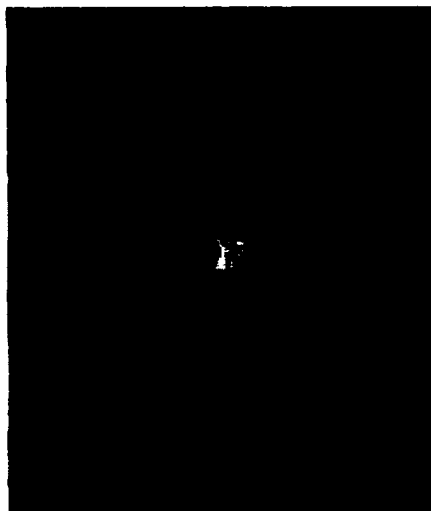
4-18-00, first 400 mm dia copy to reach 50% and be 3/4 complete.



HOE @ ~45 deg. AOI, 355 nm illumination

YAG laser

monochromator, 355 nm



$1/e^2 \sim 0.240$ mm

FWHM < 0.195 mm

$1/e^2 \sim 0.335$ mm

FWHM ~ 0.205 mm

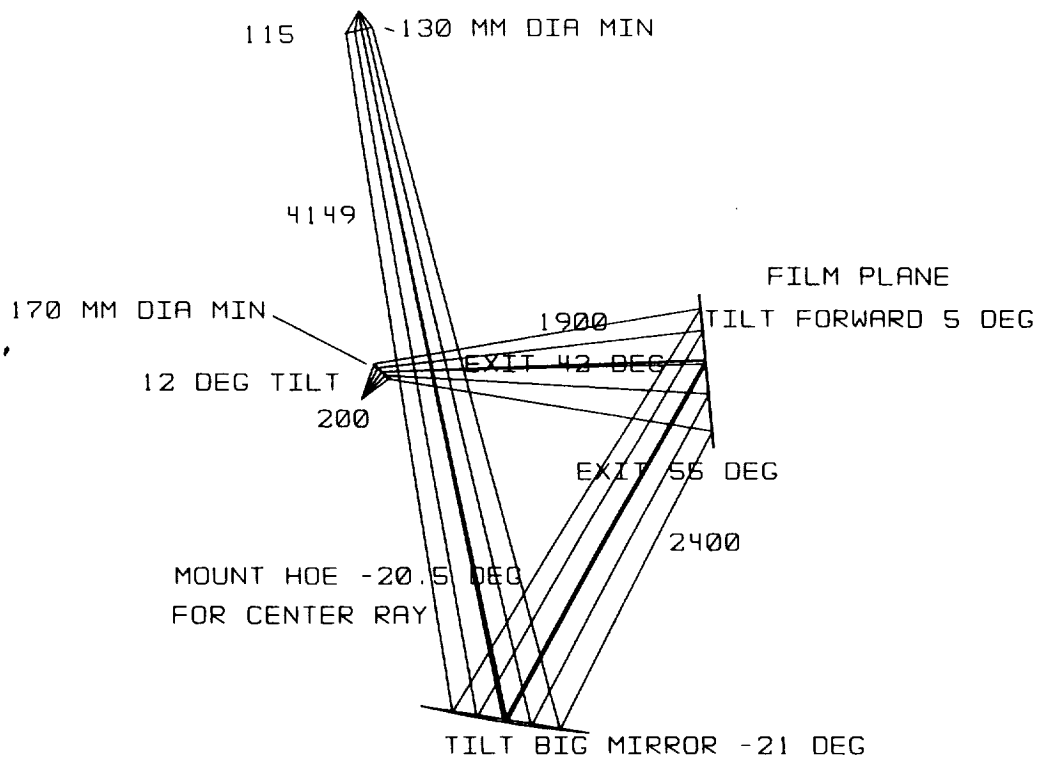
p 12

4. Large HOE alternate design:

We had so much trouble getting enough UV photons that I went ahead with a unique new design that would use the more plentiful 458 nm recording light and two HOEs for aberration correction. The recording geometry is still relatively simple with only two spatial filters, two HOEs and the large telescope mirror to shape the recording beams. This set up is shown on page 14 as N2000UV458Const-351HOE.zmx. The aberrations are still a bit large for all the work involved but it is a viable solution. One of the HOEs is nearly on axis so it needs to be made off axis and a second grating has to be made to turn it back on axis. This hoe has to be recorded originally at 514 nm using just two point sources, which is convenient for us. The basic design is shown on page 15 file # 514-351-convert.zmx. The second HOE has to be recorded at 351 nm and one beam must be converging but with a large f# so that it is still possible to make. The layouts for recording and playback are on page 16 labeled 351 to 458 convert.zmx.

The use of the 458nm design is reserved for a fall back position at this time and no work is proceeding to make the two HOEs needed to implement it. We may opt to record the second of the two HOEs prior to decommissioning our large ion laser, just as a precaution. It was very expensive and very time consuming to get even 100 mw of 351 nm light in a clean single mode and it is equally hard and risky to maintain it. The plan now is to bring on line a 5 watt 355 nm source and do the large exposures the easy way, using only the large telescope mirror to collimate one recording wave. If this plan works out we will not be needing the 351 nm source again.

Lastly we did some analysis of the 36 inch diameter physical properties using a FEA program and found that a simple aluminum ring clamped to the outer diameter made it stiff enough to be used for scanning LIDAR. The center of the HOE deflects about 100 microns, which is well within the depth of focus of any real HOE. We have 4 discs coated and a laser on its way to our facility so we may well get to see if this is the case by years end. Deflection figures for clamped ring and three point support without a ring are shown on page 17.

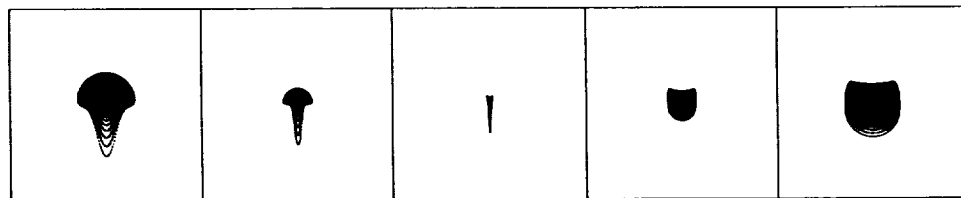


3D LAYOUT

1 METER 355 NM MASTER, CONSTRUCT AT 4579
TUE FEB 8 2000

RICHARD D RALLISON, PHOTON PLUMBER
RALCON DEV LAB, 8501 S 400 W, BOX 142
PARADISE, UT 84328, 435 245 4623
C:\ZEMAX\NASUV9981G\N2000UV458CONST-351HOE.ZMX
CONFIGURATION 1 OF 1

0.0000, 0.0000 DEG



2000.00

-400 -200 0 200 400

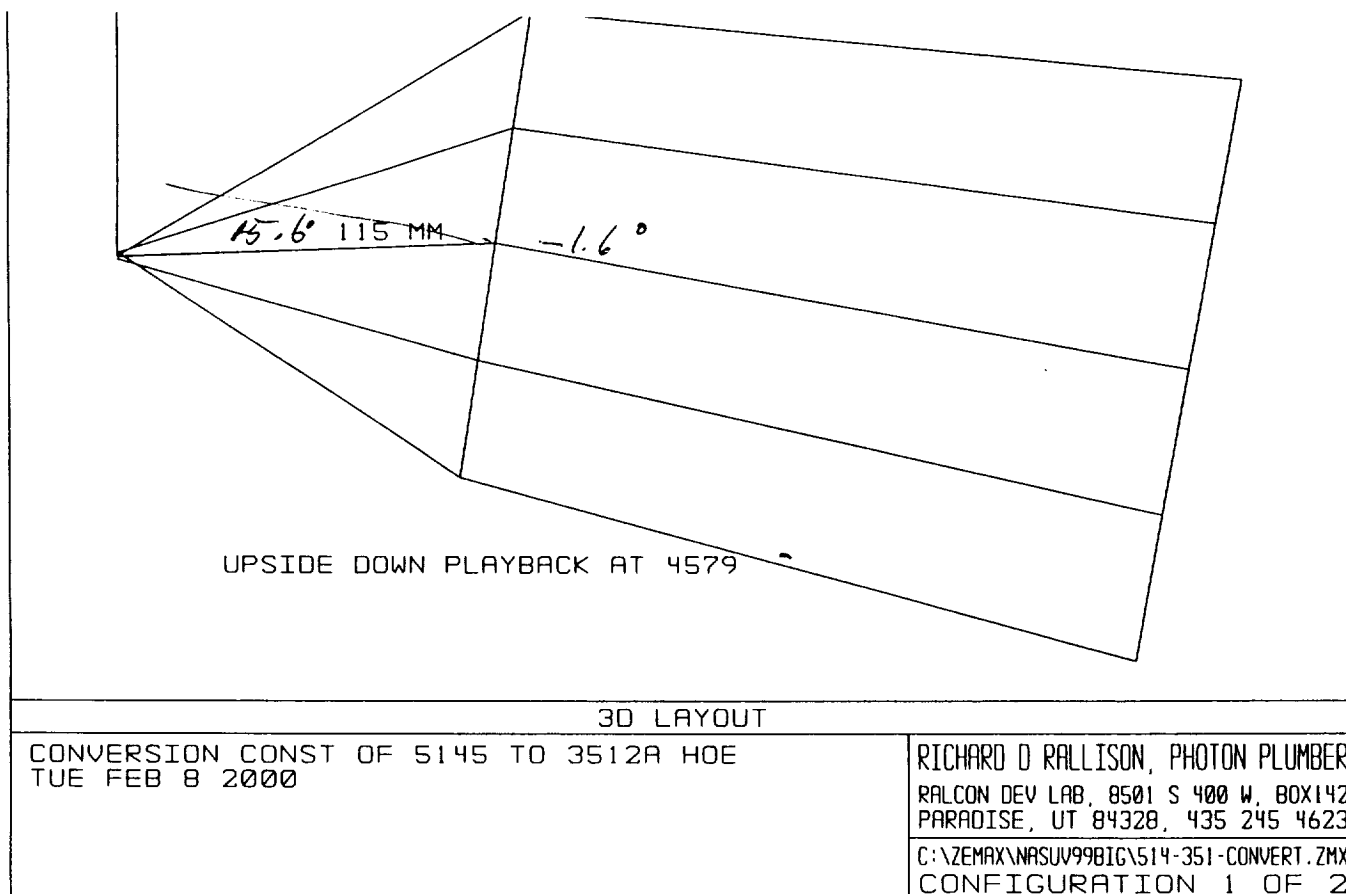
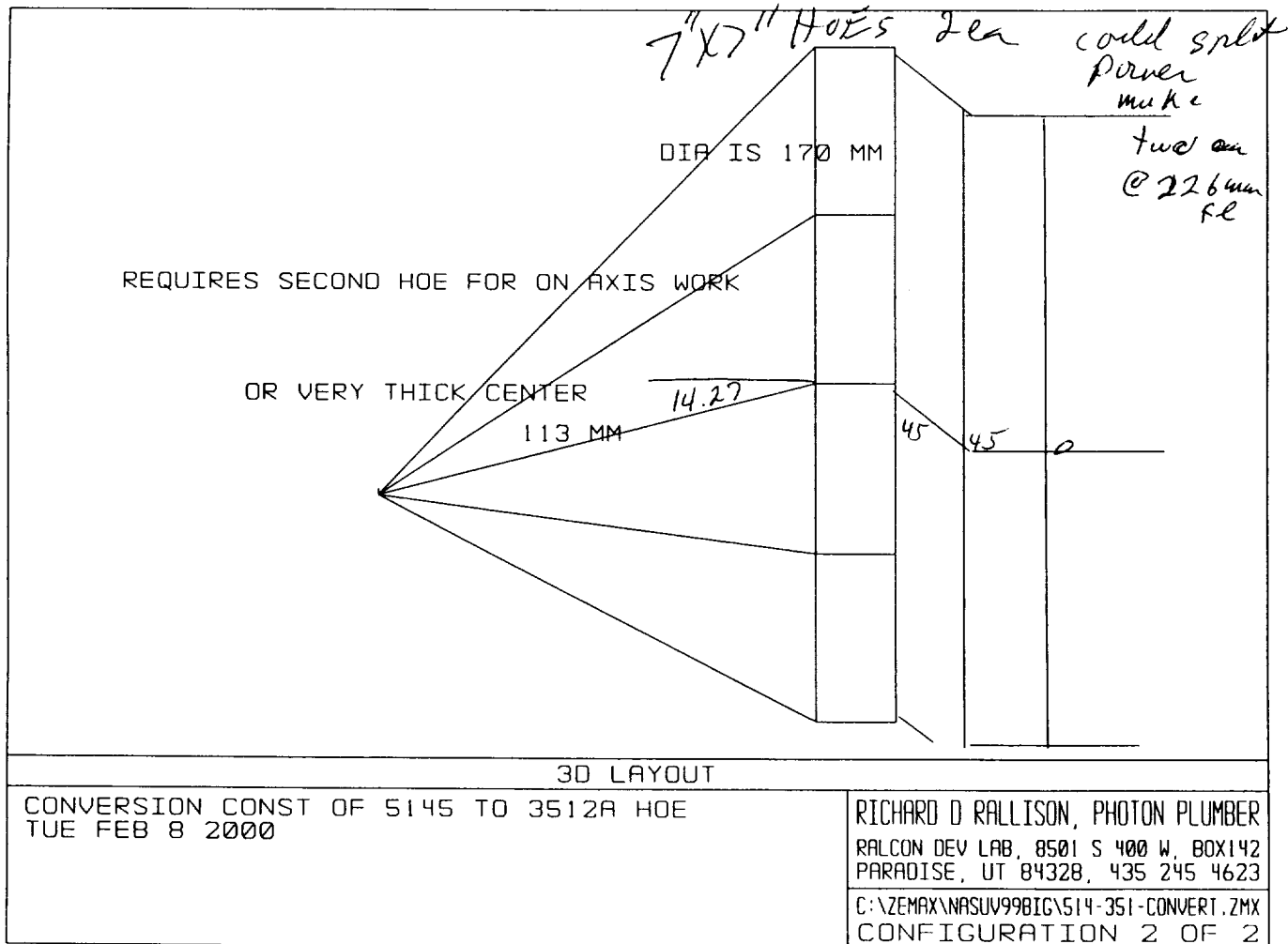
SURFACE IMA: POINT FOCUS

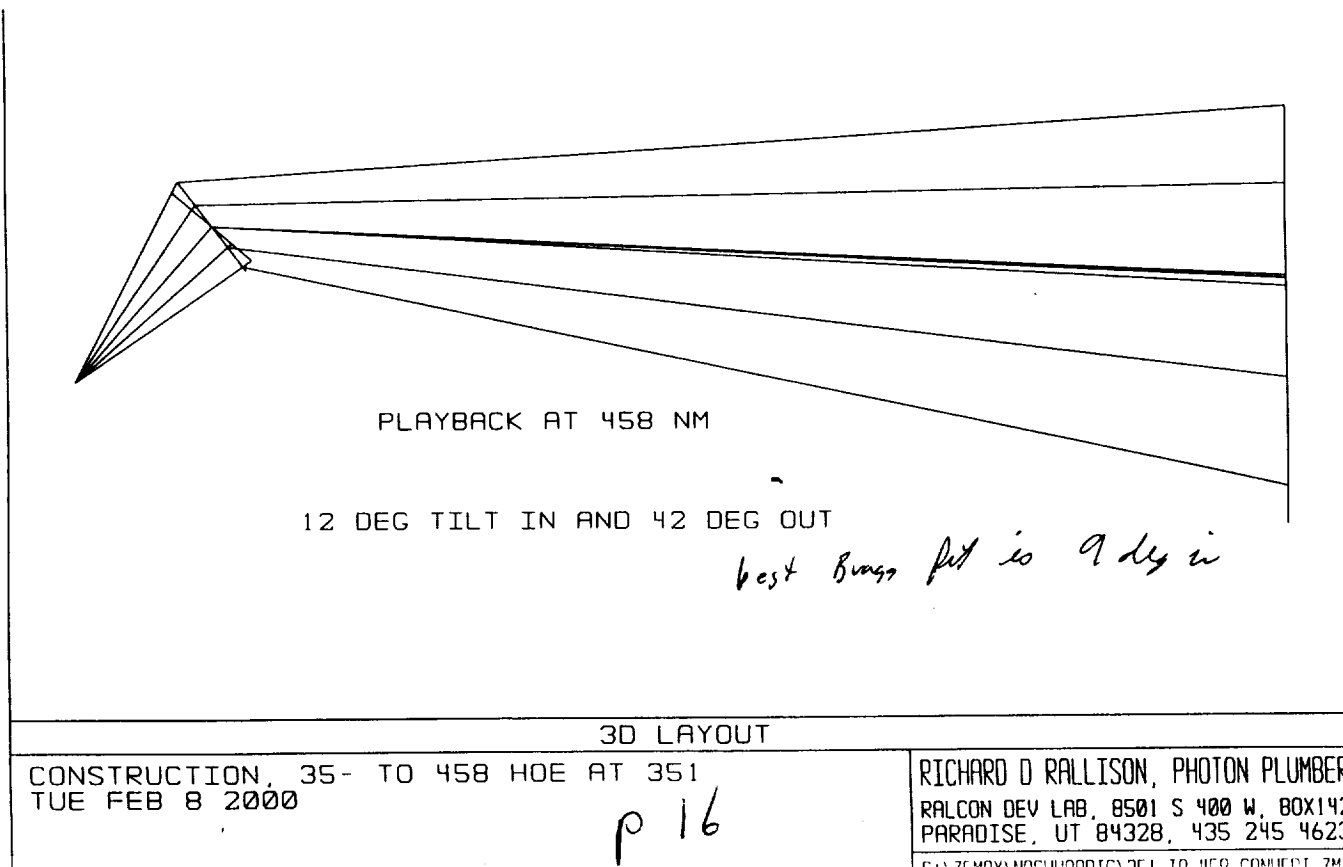
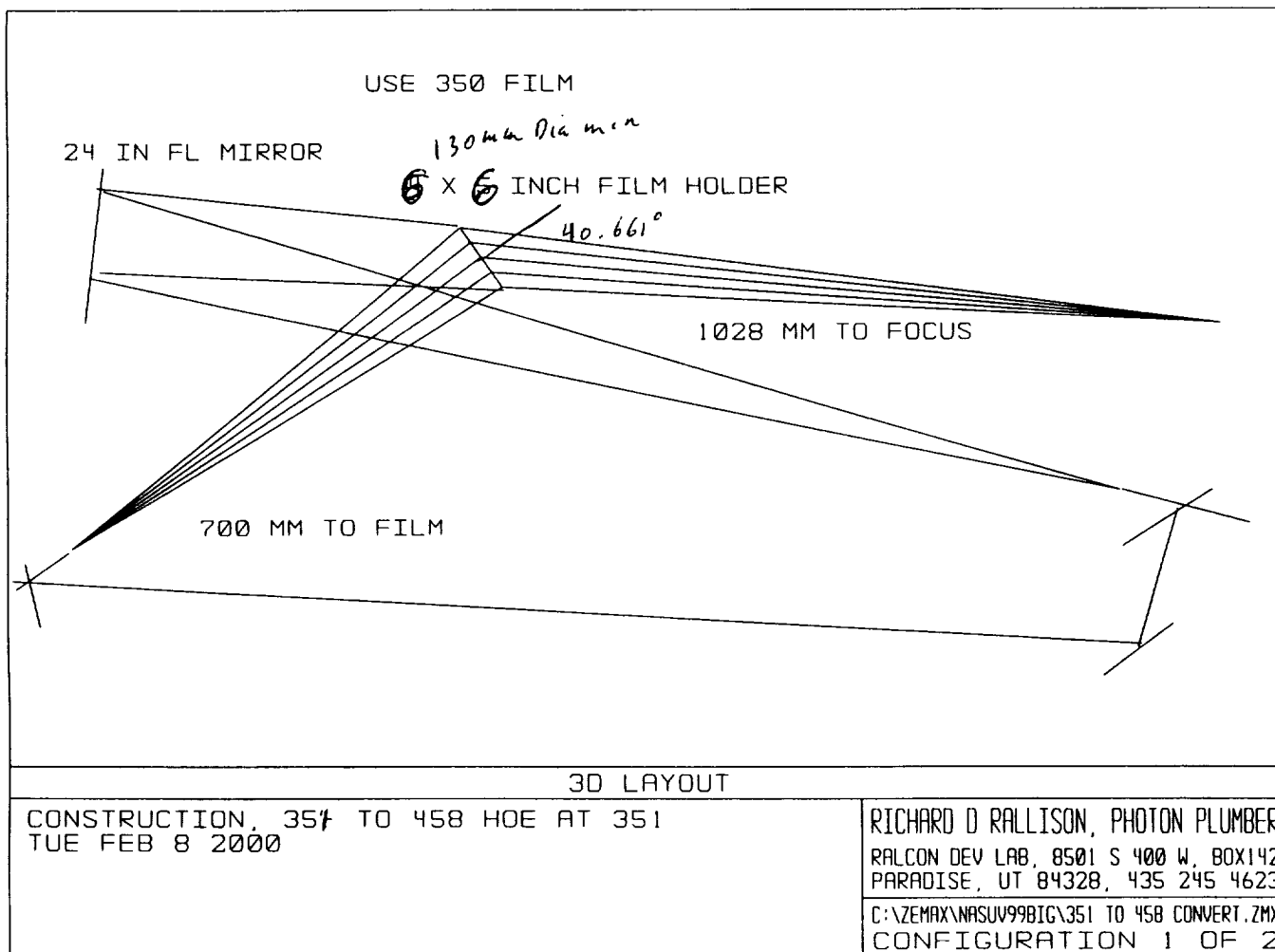
THROUGH FOCUS SPOT DIAGRAM

1 METER 355 NM MASTER, CONSTRUCT AT 4579
TUE FEB 8 2000 SPOT SIZE UNITS ARE MICRONS.

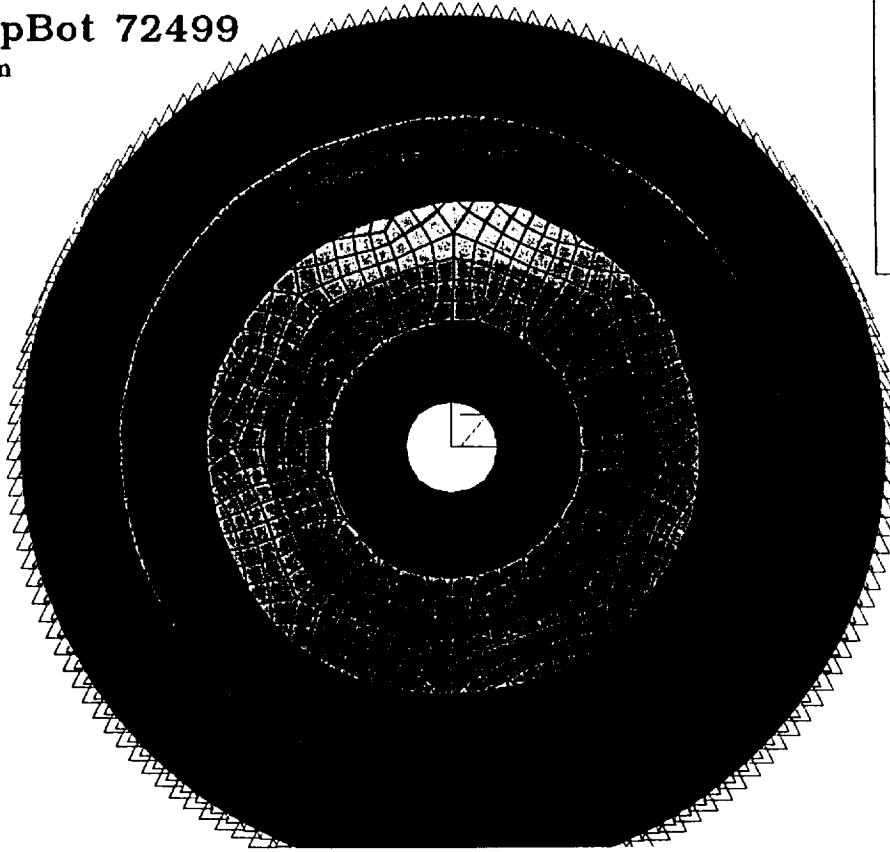
FIELD :	1
RMS RADIUS :	48.004
GEO RADIUS :	302.082
BOX WIDTH :	2000

REFERENCE : CENTROID

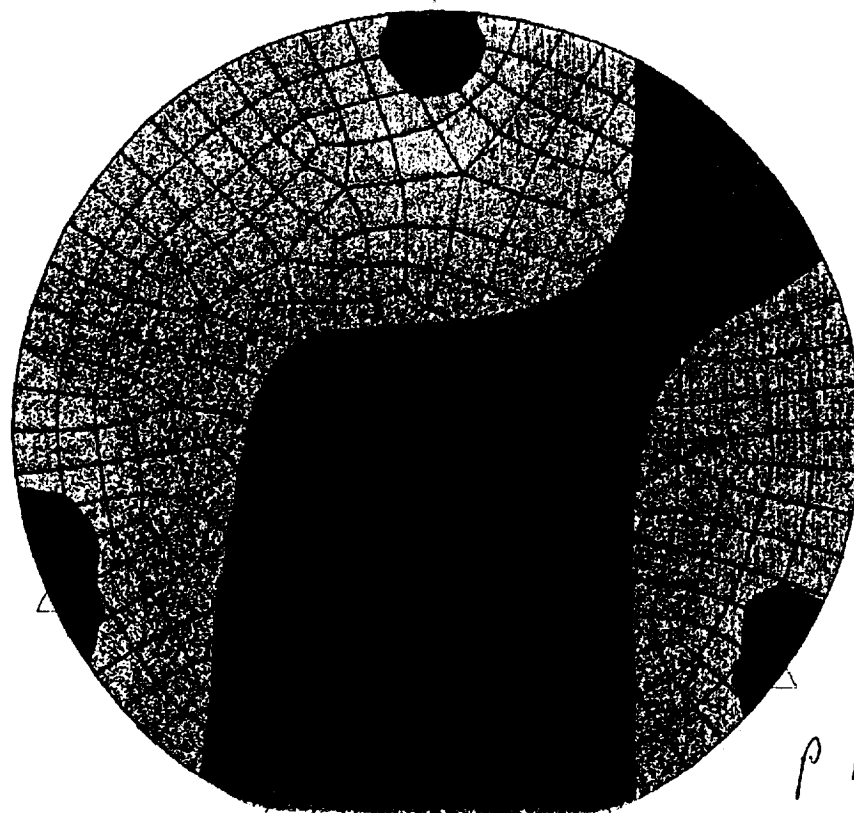
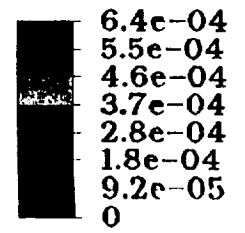




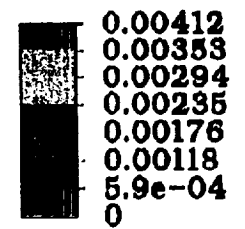
.5" ring topBot 72499
clamped @perim



Displacement



Displacement



5. Production and equipment discussion

We have delivered only 2 or 3 UV HOEs thus far and have fallen short of the intended goal in size and in dual wavelength function. Looking back, it has been fortuitous that we even made anything work in the UV region. It was our good fortune to discover that the material we work with daily was adequate for use at 355 nm, if well rinsed during processing. If we had stuck to our original plan of etching in small pieces of fused silica, we would still be trying to make the first small section in our ion mill, which is not yet operational. The original plan was far too ambitious and would take another 2 years to complete beginning where we left off this time. In order to make a HOE for the IR as well as the UV we will likely have to learn to sensitize some film to the 1064 line and we have obtained sensitizer that is reported to work in that region already. That work would also take an additional year to complete.

The aperture scanning apparatus we designed and constructed for this work turned out to be a flawless new trick that enables large apertures to be exposed with low power beams in a way that maximizes the uniformity at all points. We are now using this device to yield more uniform recordings in our commercial grating projects and it is paying off in higher yields of deliverables. The aperture scanner is just a rotating tilted plano-plano piece of glass or fused silica. It displaces the beam as it exits the laser and as it rotates it causes the aperture of each spatial filter to be scanned in a circle, causing the hot spot in the gaussian to be scanned over an appropriate power averaging diameter. The scanning hot spot can also be made smaller than the film plane and with a simple adjustment it can scan out a doughnut shape, reducing the physical stability requirement to about 1/4th of the total exposure time, except for the starting point, which we learned had to be close to the fringe locking combiner to avoid movement problems.

Environmental stability can hardly be over done with large optics and large optical path lengths. We covered solid cement walls with 12 inches of urethane foam and still had enough heat transfer to the outside during freezing weather to change the table temp by .1 degrees F per hour, which is 10 times more than could be tolerated without electronic fringe locking. We used fringe locking to keep the table dimensionally stable 24 hours a day but it could not compensate for table and component warping, just linear growth. All the components and the table itself seemed to made of rubber, rather than steel. More insulation and or active temp control is necessary to extend exposures in this room beyond 10 or 15 minutes. A five watt laser should enable 10 minute exposures. We have it on order.

6. Exposure and Processing notes.

Exposures were made successfully in 20 minutes (1200 seconds) using 150 to 200 mw of 351 nm radiation. Less than half of the light made it to the film plane and was spread over about 400 square centimeters. The recorded fringes from the 351.1 nm frequency were much stronger than the 351.4 nm but about 20 percent of the light reaching the film plane was useless. We had perhaps 40 mw of useful light times 1200 seconds equals 48 joules over .4 sq meters for a total exposure of 120 mj/cm², comparable to the exposure energy required at 514 nm. This is two orders of magnitude larger than expected, based on extrapolation of visible line sensitivity. We often expose at 458 nm with just 20 mj/cm² and I had guessed incorrectly that at 351 nm we would need only 2 mj/cm².

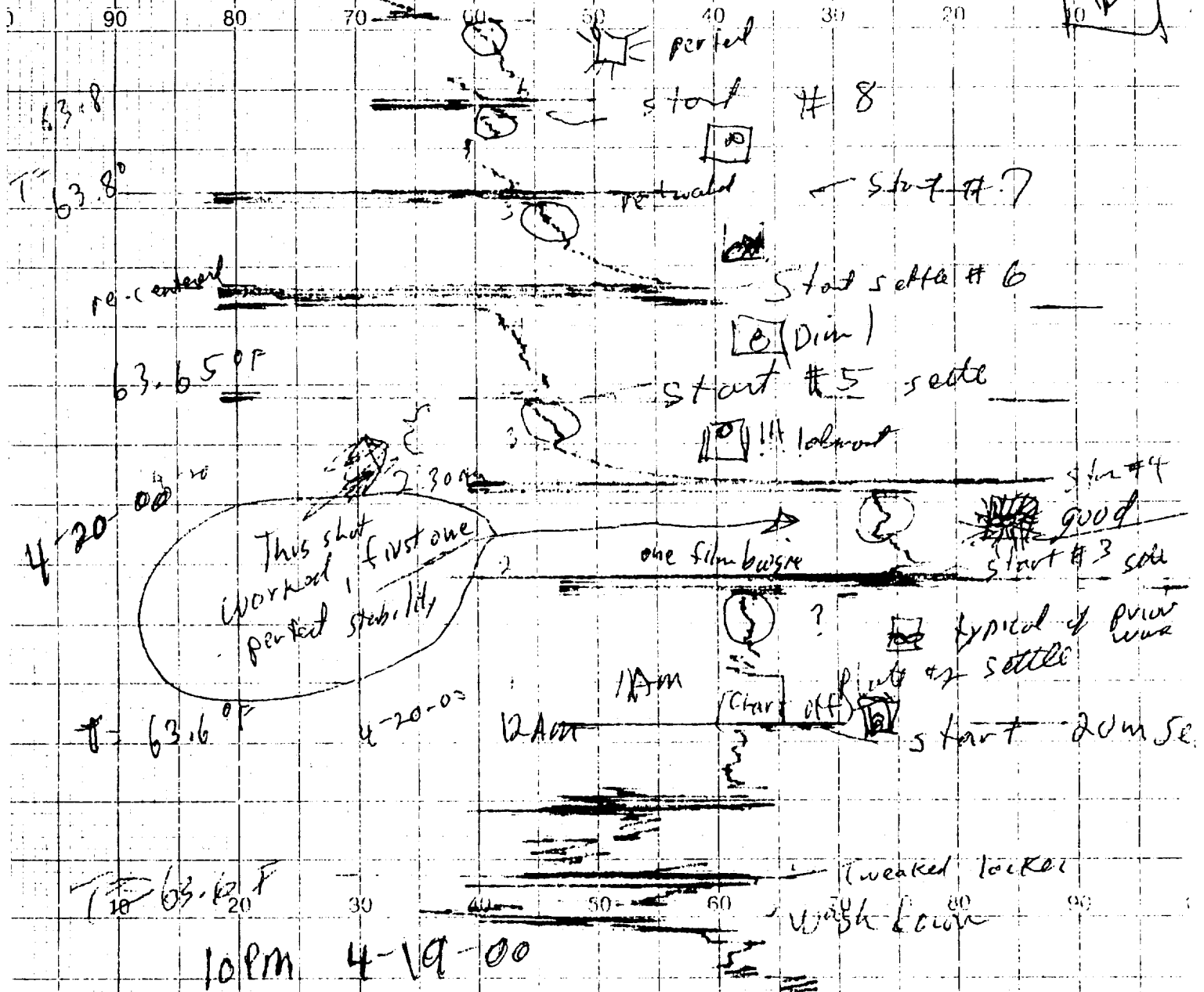
The film used for all shots of masters and for copies was our standard 10-30-350 mixture spun on at 80 RPM. It was cured and hardened for 3 hours at 170 deg F and 30% RH. The settling time was always at least 20 minutes prior to exposure and no one was allowed in the room or even in the building during exposures. The error signal from the fringe locker was constantly monitored and recorded with a strip chart recorder, a sample trace of a series of typical shots made on the night of April 19 and 20 is given on page 20. Shot numbers 3 and 8 survived without movement and number 8 became our current master. It was shot between 6 and 6:30 AM on the 20th of April, with an outside temp of 31 degrees and an inside temp of 63.8 degrees F.

A good copy of this master was made on May 8th with a 20 minute exposure at 458 nm using a 50 hz oscillating line scan directed at Brewster's angle. The calculation for this angle is given on page 21 and could only be used after baking the master for 4 hours at 230 degrees F to densify the gelatin and bring it onto the lean side of the correct Bragg angle. Normally after processing in hot alcohol the Bragg planes tend to stand up in the expanded film and baking lays them back down. A master has to be over-baked to compensate for the second generation pre-compensation exposure angle. The two corrected exposure angles at 458 nm are 57 degrees and 4 degrees. The choice to use the 57 degrees was based on the knowledge that internal reflections would all be zero at that angle provided that the polarization was in the plane of incidence, which it was.

A new process was adopted for all large plates. It is impossible to plunge a large plate into hot alcohol to get a fast uniform dehydration of the gelatin because the dehydration occurs in a fraction of a second at high temperatures. We lowered the temperature of all but the last bath to room temp and were able to get the same modulation but much better uniformity over large areas. The larger 36 inch plates have to be spin-spray developed at the last stage, but other than that they are done the same way as smaller plates. We made a big spin and spray machine for this purpose. The basic process is a 2 minute soak in Kodak fixer followed by several water baths and two cold alcohol baths for about 30 seconds each and ending with a warm alcohol bath, about 120 deg F or warmer, followed by a slow pull into dry air. All plates are baked for 2 hours before capping with Epotek 301-2 which then takes 2 days to cure.

temp dropped to freezing
 5 AM
 outside about 60 by noon
 outside AT $\approx 30^{\circ}F$

$\Delta 2cm/hr$



This is the calculation needed to determine a correct exposure angle to compensate for film expansion. The expansion causes errors in the playback angle and has to be corrected by a combination of copy angle and baking.

Tir2

File Help

Playback beam wavelength: 355 nm

Refractive index: 1.4

Record beam wavelength: 458 nm

Refractive index: 1.54

Ext input playback beam angle: 0 deg

Int angles in which Playback TIR occurs: 45.585° to 134.415°

Ext output playback beam angle: 135 deg

Media expansion factor: 1

1st Prism face normal angle: deg

Prism refractive index: 1.517

2nd Prism face normal angle: deg

Prism refractive index: 1.517

Calculate

Playback at 355.00 nm with RI 1.400

External input angle: 0.000°
Internal input angle: 0.000°

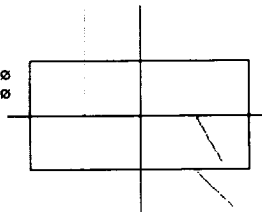
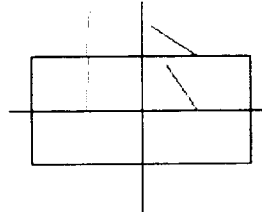
External output angle: 135.000°
Internal output angle: 149.664°

Record at 458.00 nm with RI 1.540

External input angle: 4.16507 (4 9' 54")
Internal input angle: 2.703°

External output angle: -57.1018 (-57 -6' -6")
Internal output angle: -33.040°

Internal spatial freq: 2063 1/mm (1991 1/mm at surface)
Internal grating vector angle: 74.832°

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
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13. ABSTRACT (Maximum 200 words) We have delivered only 2 or 3 UV HOEs thus far and have fallen short of the intended goal in size and in dual wavelength function. Looking back, it has been fortuitous that we even made anything work in the UV region. It was our good fortune to discover that the material we work with daily was adequate for use at 355 nm, if well rinsed during processing. If we had stuck to our original plan of etching in small pieces of fused silica, we would still be trying to make the first small section in our ion mill, which is not yet operational. The original plan was far too ambitious and would take another 2 years to complete beginning where we left off this time. In order to make a HOE for the IR as well as the UV we will likely have to learn to sensitize some film to the 1064 line and we have obtained sensitizer that is reported to work in that region already. That work would also take an additional year to complete.				
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